

# High efficiency polymer lenses for hard X-ray nanofocusing

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Nanofocusing, adiabatic, polymer compound refractive lenses combine the best of two worlds: the ease of alignment – common for refractive X-ray lenses – and a large effective aperture combined with a long working distance between exit aperture and focal plane even for hard X-rays – which is a feature usually attributed to reflective optics. This combination has long been desired in materials science related research. X-ray diffraction with nanofocused hard X-rays readily serves structural information with sub- $\mu\text{m}$  spatial resolution from crystalline and semi-crystalline materials (e.g. metals, biomaterials, synthetic compounds). That way grain orientation, residual stress profiles, crystal structure or texture can be obtained in a non-destructive analysis. Provided a long working distance focusing element, these high resolution nanodiffraction experiments can be performed in extended sample environments, with in-situ conditions and from strongly absorbing metallic samples.

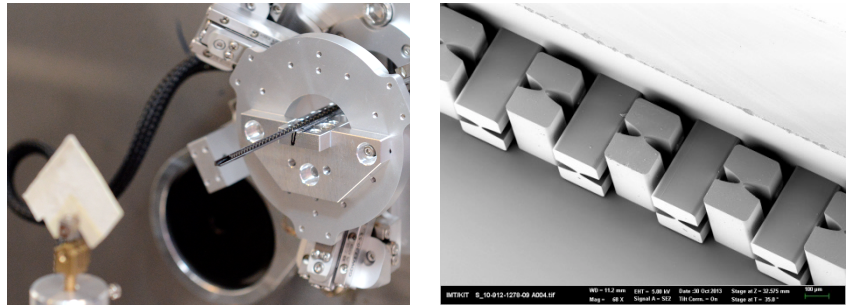


Figure 1: (left) Crossed adiabatic CRL prototype, with a working distance of 43 mm at 13 keV, installed at P03 nanofocus endstation in 2015. (right) SEM image of a CRL with varying aperture, assembled from two half lenses under  $90^\circ$ .

The adiabatic lens system presented here has a large entrance aperture of  $170\ \mu\text{m}$  and a continuously decreasing aperture adapted to the local beam diameter. In this way the exit numerical aperture of the lens stack is maximized and the focal spot diameter is minimized. Refractive polymer lenses can be fabricated via deep X-ray lithography out of SU-8, a commonly used epoxy-based negative photoresist and can be operated in air at ambient conditions. A crossed geometry, intersected lens stack provides an efficient two-dimensionally focusing close to free of spherical and astigmatic aberration. These lenses have been proven to be long time radiation stable at multiple synchrotron radiation applications and in laboratory settings up to a deposited dose of  $2\ \text{MJ}/\text{cm}^3$  [1]. At PETRA III synchrotron radiation source, the lenses have been successfully used in full field microscopy setups (beamline P05, [2]) and for X-ray nanodiffraction experiments (nanofocus endstation of P03 beamline). At P03 the lenses were used to directly demagnify the undulator source at 13 keV, yielding a focal spot size of 500 nm at a clear working distance of 43 mm. These results met the design specification and required only a short initial alignment procedure. Due to an effective aperture of  $34\ \mu\text{m}$  the transmission of the utilized lens stack was 16 %.

- [1] V. Nazmov, E. Reznikova, J. Mohr, A. Snigirev, I. Snigireva, S. Achenbach, V. Saile, Fabrication and preliminary testing of X-ray lenses in thick SU-8 resist layers, *Microsystem Technologies* 10, 716-721, (2004)
- [2] Entwicklung eines Röntgenmikroskops für Photonenenergien von 15 keV bis 30 keV, F. Marschall, KIT Scientific Publishing, Karlsruhe, dissertation, ISBN 9783731502630, 126 p., (2014)